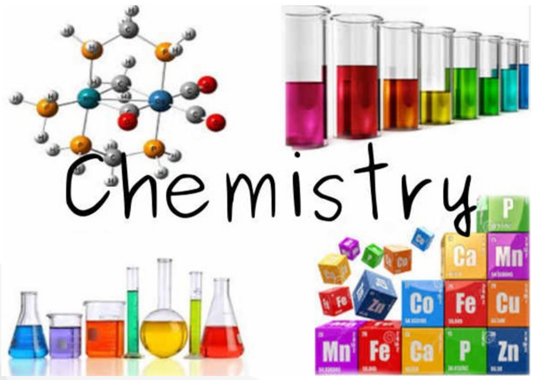
STRUCTURE OF MATTER



STRUCTURE OF MATTER

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Objectives

The subject structure of matter has several objectives. Here are some of the general objectives that might be encountered:

1. Understanding the fundamental nature of matter: The module aims to provide an in-depth understanding of what matter is made of, exploring atoms, subatomic particles and the fundamental forces that govern them.

2. Explain the basic principles of quantum physics: This includes familiarisation with concepts such as the uncertainty principle, the standard model of particle physics, and wave-particle duality.

3. Understand the structure of the atom: This involves studying the configuration of electrons around the nucleus, energy levels, atomic orbitals and packing rules.

4. Analysing the nuclear structure: This involves studying the protons and neutrons inside the atomic nucleus, and the forces that hold them together.

5. Exploring fundamental interactions: This involves understanding the four fundamental forces of nature (gravitation, electromagnetism, strong interaction and weak interaction) and their role in the functioning of the universe at microscopic scales.

6. Applying concepts to observable phenomena: Students are often encouraged to use their knowledge to explain macroscopic phenomena, such as electrical conductivity, electromagnetic radiation and the effects of electromagnetic fields.

Together, these aims are intended to provide students with a solid grounding in fundamental physics and chemistry, as well as the tools needed to understand and analyse various observable phenomena in the world around them.

to study a course “the structure of matter”, it is generally necessary to have a solid grounding in physics and a knowledge of mathematics, particularly differential and integral calculus and prior knowledge of fundamental chemistry.

prerequisite tests :

test 1 : calculate the molar mass of the following molecule, glucose, water and carbon dioxyde

I The componenets of matter

In the atomic theory it was considered that the atom was an indestructible entity, at the beginning of this century a large number of experiments follow one another which obliged to revise this theory.

In this chapter we will examine all the experiments that have served to affirm the theory of atomic structure

These experiments were carried out in three stages:

1- Discovery of the electrical nature of matter

2- Discovery that the atom consists of a nucleus and particles

3- Discovery of mechanical laws that show the behaviour of elements in the atom

By the end of this section, you will be able to:

• State the postulates of atomic theory

• Use postulates of atomic theory to explain the laws of definite and multiple proportions

1. Discovery of the electric nature of matter: Faraday's experience, The relationship between matter and electricity

The purpose of the FARADAY experiment is the conclusion of the existence of a relationship between matter and electricity.

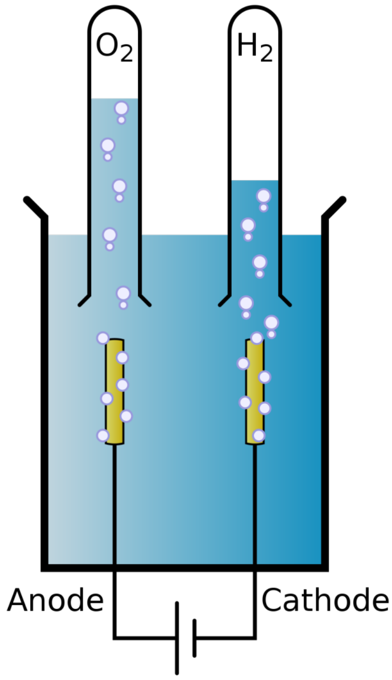
During the electrolysis of water, hydrogen is released from the electrode (+) (anode) while oxygen is released from the electrode (-) (cathode).

Figure shows the distribution and movement of ions during electrolysis.

water electrolysis: $H_2O \rightarrow H_2 + ½\, O_2$

At anode (+): $O^{2-} \rightarrow ½\, O_2 + 2\, e-$

At cathode (-): $2H^{+} + 2\, e- \rightarrow 2H_2$



Electrolysis of water

2. Matter constituents

2.1. Electron

Experience of J.J Thomson (1897): The discovery of electron [4]

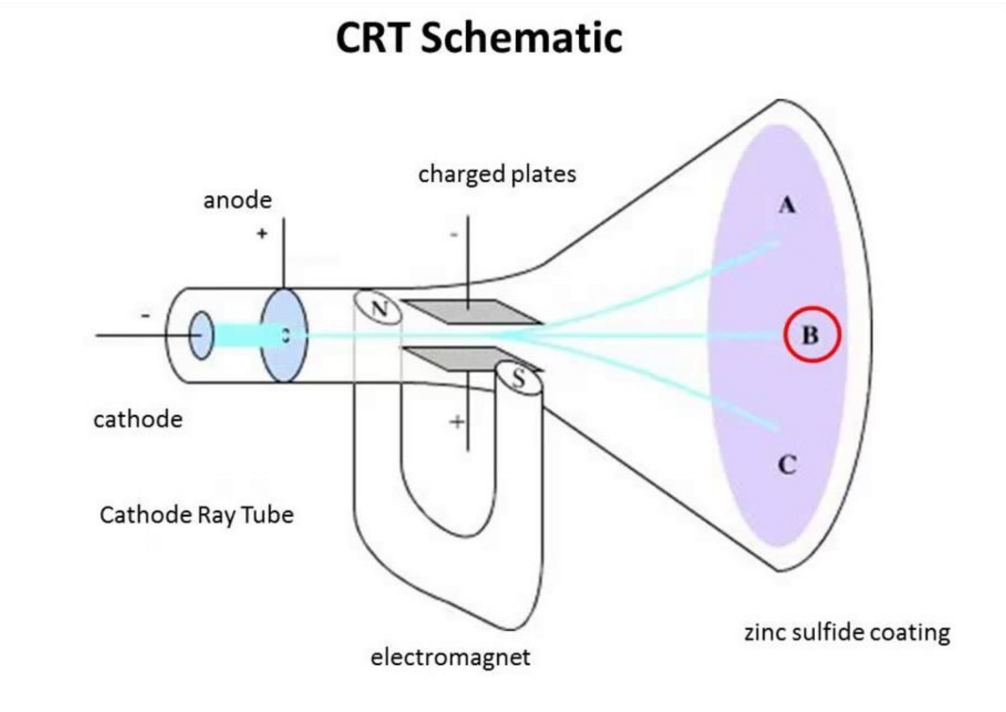
The aim of this experiment is the demonstration of the existence of negatively charged particles and the calculating of the mass load ratio ***(e/m)***

- In a first part, a beam of cathodic ray is subjected to the action of an electric field (2 plates of a capacitor); it is noted that there is appearance of a luminous point C on the screen.

This explains why these rays contain negatively charged particles (attraction of charges (−) towards the plate (+) of the capacitor).

- In a second part of the experiment, we use a magnetic field (magnet) we notice the appearance of a luminous point A on the screen. This further proves the existence of charges (-) in the cathodic ray (deviation of radiation towards the pole N which is the pole (+) of the magnet.

- In a third experiment the two fields are submitted at the same time, it is noted that there is no deviation of cathode radiation (appearance of a luminous point at point B)



Conclusion:

• Electrons are part of the constitution of all atoms.

• By combining the intensity of the electric and magnetic fields, the cathode ray beam may not deviate from its original path.

• Thomson thus determined the charge-to-mass ratio of the particles:

$e/me = 1{,}76 \times 10^{11}$ C/Kg

Millikan's experience (1909): measurement of the electron charge:

The purpose of this experiment is to determine the charge of the electron

- Sprayer: injects droplets of non-volatile liquid

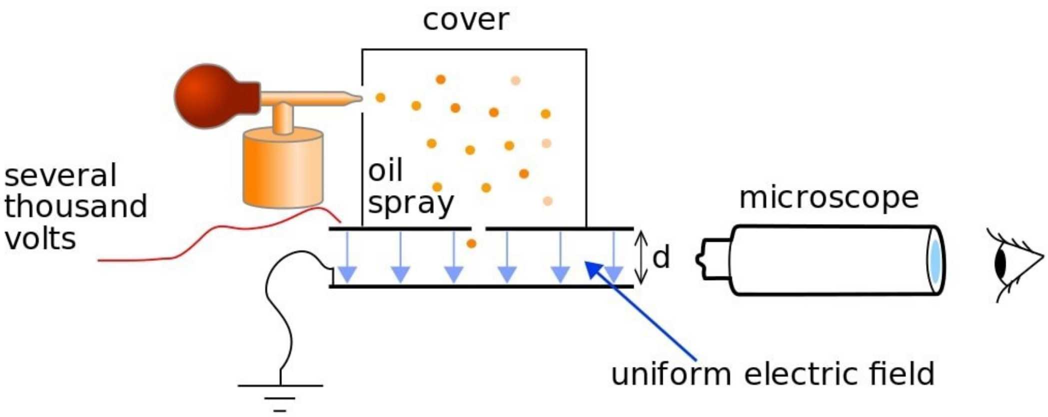
- Microscope: used to measure droplet speed between capacitor plates

By means of X-rays these droplets are charged, when the electric field is applied the droplet rises and when the field is cut it goes down.

There are several forces that are present in each type of movement

1- In a climb E is different from 0

2- In a descent E is equal to 0



- From the force of the electric field necessary to cancel the force of gravity (weight) on the droplets, Millikan was able to determine the values of the particle charges.

- As each oil droplet contains several additional electrons, it assumed the smallest charge difference between two droplets

- Modern value is -e with e = $1,602 \times 10^{-19}$ C

C: coulomb, the SI unit of electric charge

- It is considered that −e is a "unit" of negative charge, and that e, called fundamental charge, is a "unit" of positive charge

The electron mass was calculated by combining this value with the ratio

e/me = $1,76 \times 10^{11}$ C/Kg,

calculated by Thomson we find: me = $9,109 \times 10^{-31}$ Kg

3. Planetary Atomic Model of Rutherford (1909):

3.1. Discovery of the nucleus

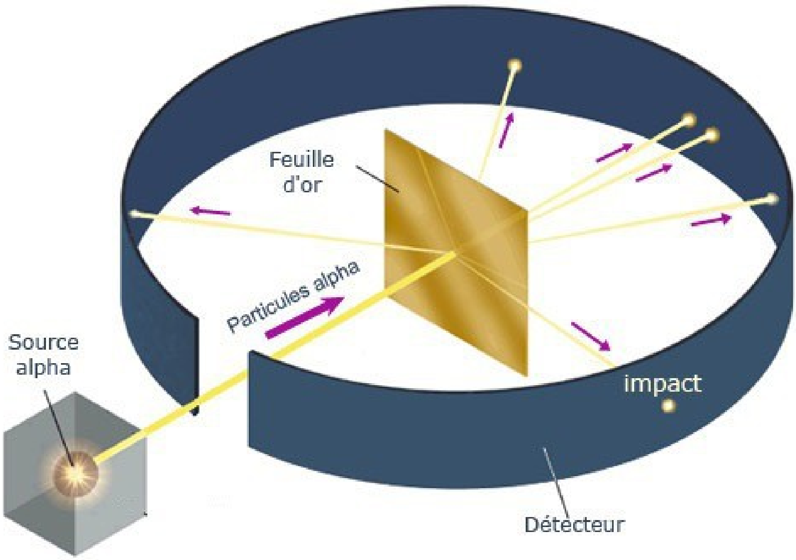
A thin gold leaf is bombarded by α (charged +) particles emitted by a radium source. The mass of each atom of the gold leaf must be evenly distributed over the entire atom. Therefore, when particles α hit the leaf, they are expected to slow down and change direction only by small angles as they pass through the leaf.

However, in doing so, Rutherford and his assistants make these observations:

• Most particles pass through the gold leaf without deviation as if they had never met the gold atoms.

• Several particles α are slightly deflected during the gold leaf traverse.

• Some particles α (1 in 20,000 to 30,000) appear to be back.[5]



Conclusion:

1-The particles have passed through the leaf without being deflected, most of the space in the atom is empty.

2-The deviation of some positively charged α particles must be due to the enormous repulsion force. This suggests that the positive charge is not uniformly distributed throughout the atom as proposed by Thomson. The positive charge must be concentrated in a very small volume to deflect the positively charged α particles.

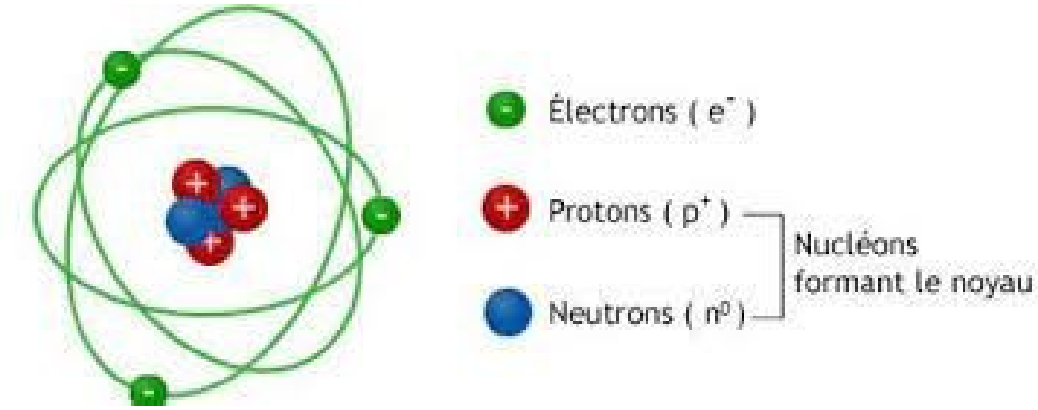
3-Rutherford calculations show that the volume of the nucleus is very small in relation to the total volume of the atom and that the radius of an atom is about 10^{-10} m, while that of the nucleus is 10^{-15} m.

4. Presentation and Characterization of The Atom

Atoms are the particles that make up matter. In the center of the atom, there is a nucleus composed of protons and neutrons. Around this nucleus are very fast moving particles, electrons. In an atom there are as many positively charged protons as negatively charged electrons, an atom is electrically neutral.

4.1. An Atom

The atom is an electrically neutral set characterized by a number of electrons that revolve around the nucleus and a number of nucleons that make up its nucleus



An atom or chemical element may be presented by the following symbol: ${}^{A}_{Z}X$

Z is the atomic number or the number of protons in the nucleus.

• For the neutral atom, Z = number of electrons

if element has positive (X^{+Ze}, ***cation***) or negative (X^{-Ze}) charge, the number of electrons is:

number of electrons = Z- Ze (for cation)

number of electrons = Z+Ze (for anion)

number of electrons = Z – charge

A is the Mass Number it represents the number of nucleons (protons + neutrons)

A determines the number of neutrons N, that an atom has:

N = A – Z

4.2. The nucleus

The nucleus contains two types of particles:

• Proton that has a charge of 1.60×10^{-19} Coulomb which corresponds to the elementary charge for a mass of 1.73×10^{-27} Kg

• Neutron that has zero charge for a mass of 1.675×10^{-27} Kg

The nucleus has a positive charge. Neutrons and protons are the nucleons that are held together by strong interaction.

• Electron that has a charge of 1.60×10^{-19} Coulomb its charge is negative and mass of 9.109×10^{-31} kg, it is therefore 1800 times less heavy than the proton.

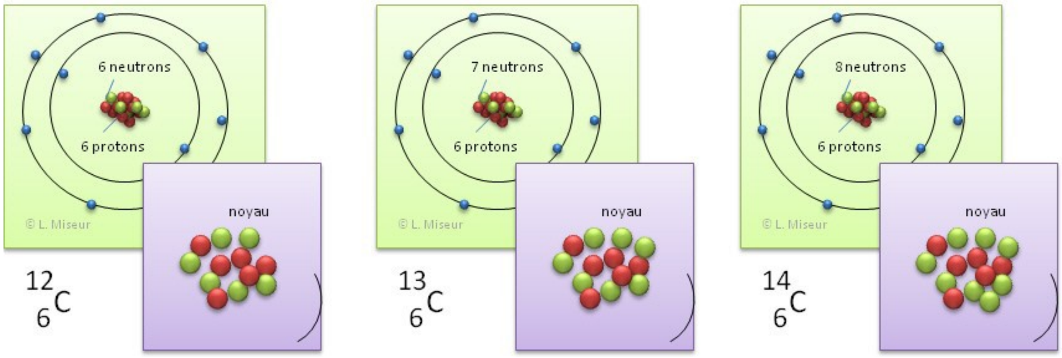
The mass of an atom is therefore substantially the same as the mass of its nucleus.

5. Isotopy and Relative Abundance of Different Isotopes

5.1. Isotopes

When two elements of the same symbol have the same atomic number (Z) but the mass number (A) is different they are called isotopes.

Example: isotopes of carbon



5.2. Relative Abundance of Different Isotopes

The natural abundance (x) or natural isotope content represents the percentage in number of atoms of each of the isotopes present in the natural mixture.

Example

Isotopes	Carbon 12	Carbon 13	Carbon 14
X (%)	98,9	1,09	0,01

5.3. Isotope Separation, Determination of The Atomic Mass And The Average Mass Of An Atom

The mass spectrum separates and measure the mass of isotopes of the same element. There are many types of mass spectrometer:

- ASTON Mass Spectrometer

- DEMPSTER Mass Spectrometer

- BAINBRIDGE Mass Spectrometer

Isotopes are subject to the effect of electric and magnetic fields

The most practical method is to measure the ratio q/m

q: the isotope charge m: isotope mass

Description of a mass spectrometer:

A device in which ions are produced from a sample or they will be:

. Detected and separated according to their ratio (load/mass);

. Expressed in terms of relative abundance

Bainbridge Spectrograph:

This Bainbridge spectrograph consists of four parts:

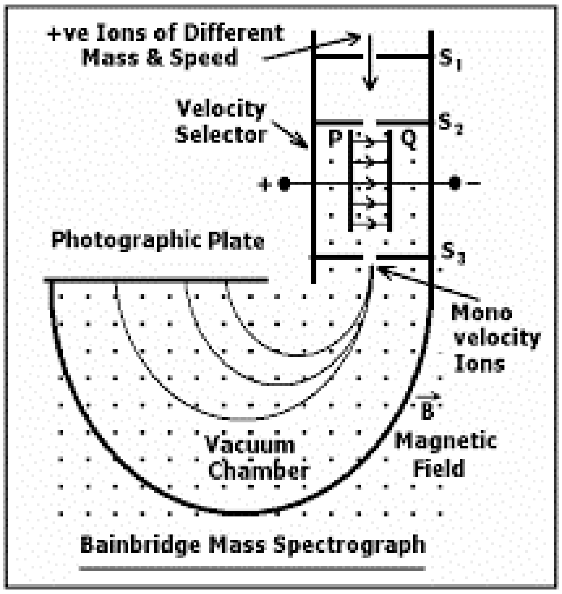
- A source of ions,

- The speed filter,

- The analyzer

- The ion detector (photographic plate).

Several peaks with different intensities were recorded by the detector. This is mainly due to the difference in the trajectory speed which depends on the atomic mass of each isotope (A1, A2,...) and the relative abundance.



6. Nuclear Binding and Cohesion Energy

6.1. Binding Energy

It is defined as the energy required to form any nucleus from proton and neutron. It is described by the following reaction:

$Z + N \rightarrow + E$

This energy E is always negative

6.2. Cohesion Energy

This is the energy required to destroy a nucleus (neutron and proton).

This energy is always positive.

(B= - E). This energy is represented by the following reaction:

${}^{A}_{Z}X + B \rightarrow Z + N$

7. . Nuclear Stability

7.1. Determination of Cohesive Energy (Aston's Curve)

The cohesion energy per nucleon (B') is given by the following relation

B=B/A A: the mass number and B cohesion energy.

This energy (B') is expressed by the following unit (Mev/nucleon):

1 Mev = 10^6 ev = 1,6 10^{-19} Joule.

1 ev: is defined as the energy acquired by an electron accelerated by a difference of potential d.d.p = 1volt. 1 ev= 1,6 10^{-19} . 1 = 1,6 10^{-19} Joule.

The figure represents the variation of the cohesion energy per nucleon as a function of mass number A.

This curve is called Aston curve.

This aspect shows the evolution of the stability of the nucleus as a function of A and also makes it possible to easily visualize the most stable element. From this curve, energy (B') is strictly less than 8.9 Mev/nucleon (B <8.9Mev /nucleon) regardless of the element considered.

The resulting curve presents:

- a maximum of A = 60, the corresponding atoms being the most stable atoms (8,8 Mev/nucléon);

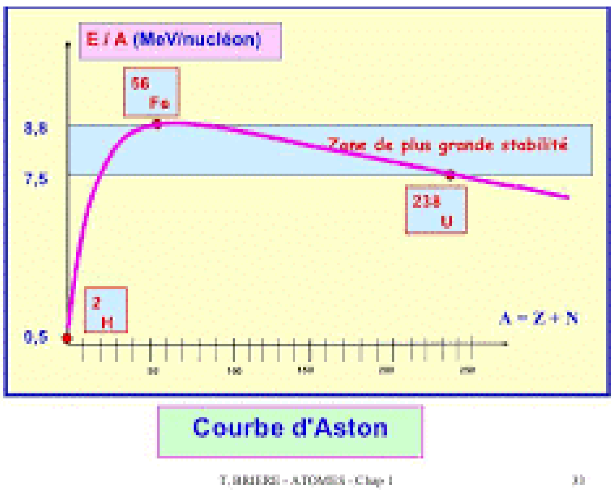
- A decline in stability beyond A= 60 :

- a very important slope for the zone of light atoms of A < 15, rapid growth;

- a much gentler slope, for atoms A > 15 ;

Atoms that B< 7,5 MeV / nucleon, will seek to stabilize and approach the maximum stability zone 58 < A< 80.

These results indicate the possibility of two different processes: fusion concerns (light atoms) and fission (heavy atoms).



8. exercises

Exercise 1

Select the correct answer(s) from the following:

1 – The theory of the atom was proposed by:

a – E. Rutherford; b – J. Dalton; c – J. Chadwick; d – J. J. Thomson

2 – Rutherford's experiment allowed us to conclude that:

a- The atom is empty; b- Atomic mass is distributed throughout the whole atom;

c – The center of the atom has a positive charge; d – The center of the atom is empty

3 – According to the Rutherford experiment, the volume of the nucleus relative to the volume of the atom is:

a – 25% ; b – 50% ; c – negligible ; d – 75%

4 – The number of protons of an atom is called:

a – Atomic mass; b – Protons number ; c – Mass number ; d – Atomic number

5 – Isotopes of an element have:

a– The same number of protons and neutrons; b - The same number of neutrons and a different number of protons; c- The same number of protons and a different mass number;

d – The same number of protons and a different number of neutrons.

II Exercises

Exercise 1

We assume that the mass of the phosphorus atom 15P is equal to the sum of the masses of the particles that make it up.

1) What is the mass of the nucleus of a phosphorus atom?

2) What is the mass of the electron cloud of a phosphorus atom?

3) What is the mass of a phosphorus atom? What conclusion do you draw?

Exercise 2

The mass of all the electrons in the iron atom is $2{,}366.10^{-29}$ kg.

1- Knowing that one electron has a mass of $9{,}1.10^{-31}$ kg, how many electrons does an iron atom have?

2- What is the number of positive charges carried by the nucleus of the iron atom?

3- Deduce the atomic number of the iron atom. The mass of an iron atom is $9{,}3.10^{-26}$ kg.

4- Calculate the number of iron atoms that make up an iron nail of 2,5 g.